JC07 Rec'd PCT/PTO 02 NOV 2001

FORM PTO-1390 (REV 10-94) U S DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE		ATTORNEY'S DOCKET NUMBER 9997.38USWO
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371		U S APPLICATION NO (If known, see 37 C F R 1 5) Unknown 10/009337
INTERNATIONAL APPLICATION NO. PCT/BE00/00049	INTERNATIONAL FILING DATE 3 May 2000	PRIORITY DATE CLAIMED 3 May 1999

TITLE OF INVENTION

DEVICE AND METHOD FOR A LASER BLOCKED-MODE

APPLICANT(S) FOR DO/EO/US

PEREMANS et al.

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. [X] This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. [ ] This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. [ ] This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(l).
4. [X] A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. [X] A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. [X] is transmitted herewith (required only if not transmitted by the International Bureau).
   b. [X] has been transmitted by the International Bureau.
   c. [ ] is not required, as the application was filed in the United States Receiving Office (RO/US)
6. [X] A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. [X] Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. [ ] are transmitted herewith (required only if not transmitted by the International Bureau).
   b. [ ] have been transmitted by the International Bureau.
   c. [ ] have not been made; however, the time limit for making such amendments has NOT expired.
   d. [X] have not been made and will not be made.
8. [ ] A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. [X] An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
10. [X] A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern document(s) or information included:

11. [X] An Information Disclosure Statement under 37 CFR 1.97 and 1.98, Form 1449, 7 references, International Search Report.
12. [X] An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. [X] A FIRST preliminary amendment.
    [ ] A SECOND of SUBSEQUENT preliminary amendment.
14. [ ] A substitute specification.
15. [ ] A change of power of attorney and/or address letter.
16. [ ] Other items or information:

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U.S. APPLICATION NO (If known, see 37 C F R 1 5)	INTERNATIONAL APPLICATION NO	ATTORNEY'S DOCKET NUMBER
Unknown 10/009337	PCT/BE00/00049	9997.38USWO

17. [X] The following fees are submitted:	CALCULATIONS	PTO USE ONLY
BASIC NATIONAL FEE (37 CFR 1.492(a) (1)-(5)): Search Report has been prepared by the EPO or JPO....................**$890.00** International preliminary examination fee paid to USPTO (37 CFR 1.492(a)(1))....................**$710.00** No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2))....................**$740.00** Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(3)) paid to USPTO.................... **$1040.00** International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4)....................**$100.00**		
ENTER APPROPRIATE BASIC FEE AMOUNT =	**$890.00**	
Surcharge of **$130.00** for furnishing the oath or declaration later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	**$**	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	11 -20 =		X $18.00	**$**	
Independent claims	3 -3 =		X $84.00	**$**	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ $260.00	**$**	

TOTAL OF ABOVE CALCULATIONS =	**$890.00**	
Reduction by 1/2 for filing by small entity, if applicable. Small entity status is claimed pursuant to 37 CFR 1.27	**$445.00**	
SUBTOTAL =	**$445.00**	
Processing fee of **$130.00** for furnishing the English translation later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(f). +	**$**	
TOTAL NATIONAL FEE =	**$445.00**	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). $40.00 per property +	**$ 40.00**	
TOTAL FEES ENCLOSED =	**$485.00**	
	Amount to be: refunded	**$**
	charged	**$**

a. [X] Check(s) in the amount of <u>$445.00 and $40.00</u> to cover the above fees is enclosed.

b. [ ] Please charge my Deposit Account No. __________ in the amount of $ ________ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. [X] The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. <u>13-2725</u>.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO
John J. Gresens
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SIGNATURE: JMJ Gresens

NAME: John J. Gresens

REGISTRATION NUMBER: 33,112

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S/N unknown PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant:	PEREMANS et al.	Docket No.:	9997.38USWO
Serial No.:	unknown	Filed:	concurrent herewith
Int'l Appln No.:	PCT/BE00/00049	Int'l Filing Date:	3 May 2000
Title:	DEVICE AND METHOD FOR A LASER BLOCKED-MODE		

CERTIFICATE UNDER 37 CFR 1.10
'Express Mail' mailing label number: EV037644454US
Date of Deposit: 2 November 2001
I hereby certify that this correspondence is being deposited with the United States Postal Service 'Express Mail Post Office To Addressee' service under 37 CFR 1.10 on the date indicated above and is addressed to the Assistant Commissioner for Patents, Washington, D.C . 20231.

By: [signature]
Name: Chris Stordahl

PRELIMINARY AMENDMENT

Box PCT
Assistant Commissioner for Patents
Washington, D. C. 20231

Dear Sir:

In connection with the above-identified application filed herewith, please enter the following preliminary amendment, which is based on claims amended in prosecution of the international application and published in the International Preliminary Examination Report, a copy of which is enclosed herewith:

IN THE ABSTRACT

Insert the attached Abstract page into the application as the last page thereof.

IN THE SPECIFICATION

A courtesy copy of the originally-filed PCT specification is enclosed herewith, but the World Intellectual Property Office (WIPO) copy should be relied upon if it is already in the U.S. Patent Office.

IN THE CLAIMS

Please amend the following claims as indicated below. A marked-up copy of all claims is attached for reference.

4. (amended) Device according to Claim 2, characterized in that said non-linear crystal is a BBO crystal.

6. (amended) Device according to Claim 1, characterized in that the intensity limiter (4) and the non-linear optical means (10) are placed on either side of the active gain medium (5).

7. (amended) Device according to Claim 1, characterized in that the intensity limiter (4) is placed between the non-linear optical means (10) and the active gain medium (5).

8. (amended) Device according to Claim 1, characterized in that the active gain medium is an Nd:YAG crystal.

9. (amended) Device according to Claim 1, characterized in that the non-linear optical means (10) has a reflection coefficient of the radiation at the second harmonic ($\omega 2$) which is greater than the reflection coefficient of the radiation at the fundamental frequency ($\omega 1$).

REMARKS

The above preliminary amendment is made to remove multiple dependencies from claims 4, and 6-9.

A new abstract page is supplied to conform to that appearing on the publication page of the WIPO application, but the new Abstract is typed on a separate page as required by U.S. practice.

Applicant respectfully requests that the preliminary amendment described herein be entered into the record prior to calculation of the filing fee and prior to examination and consideration of the above-identified application.

If a telephone conference would be helpful in resolving any issues concerning this communication, please contact Applicant's primary attorney-of record, John J. Gresens (Reg. No. 33,112), at (612) 371.5265.

Respectfully submitted,

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Dated: 2 November 2001

By ______________________
John J. Gresens
Reg. No. 33,112

JJG/kjr

9997.38USWO

ABSTRACT

The invention relates to a device for a laser blocked-mode, especially for a pulsed laser, comprising a cavity resonator (20) which is defined by a first mirror (1) and a second mirror (8), and fitted with an amplifying active laser medium (5) for the amplification of a beam of laser radiation of a fundamental frequency (ω1) and a solid, non-linear optic means (10) comprising at least said second mirror (8) for reversible conversion of the radiation of the fundamental frequency (ω1) into radiation of a harmonic frequency (ω2) whereby said non-linear optic means (10) has a reflection factor which increases with the intensity of the radiation of a fundamental frequency. The invention is characterized in that said device also comprises a solid intensity limiter (4) in the cavity resonator (20), whereby the transmission factor of the laser radiation decreases with the intensity of said radiation. The invention also relates to a method for a laser blocked-mode, especially for a pulsed laser, using said device.

MARKED UP COPY OF CLAIMS

4. Device according to Claim 2[or 3], characterized in that said non-linear crystal is a BBO crystal.

6. Device according to [one of the preceding] C[c]laim[s] 1, characterized in that the intensity limiter (4) and the non-linear optical means (10) are placed on either side of the active gain medium (5).

7. Device according to [one of the preceding] C[c]laim[s] 1, characterized in that the intensity limiter (4) is placed between the non-linear optical means (10) and the active gain medium (5).

8. Device according to [one of the preceding] C[c]laim[s] 1, characterized in that the active gain medium is an Nd:YAG crystal.

9. Device according to [one of the preceding] C[c]laim[s] 1, characterized in that the non-linear optical means (10) has a reflection coefficient of the radiation at the second harmonic ($\omega 2$) which is greater than the reflection coefficient of the radiation at the fundamental frequency ($\omega 1$).

DEVICE AND PROCESS FOR MODE-LOCKING A LASER

Subject of the invention

The present invention relates to a device and to a process for mode-locking a laser, and in particular a laser functioning in pulsed mode.

State of the art

A laser cavity consists of an optical gain medium placed inside a resonator delimited by two mirrors oriented in auto-collimation, that is to say face to face. When the gain medium is activated, an optical oscillation is maintained in the cavity, such that the device can emit a light beam characterized by a very high spatial and spectral brightness.

The mode-locking of a laser cavity consists in forcing short light pulses to circulate in said resonator, so as to generate pulses of high peak intensity and with a pulse length typically of less than 100 picoseconds, which may be upto a few femtoseconds depending on the gain medium used.

Lasers which may be distinguished include lasers of the continuous type in which the gain medium is permanently activated, that is to say over time scales of from several seconds to several hours. A continuous mode-locked laser may thus generate short pulses at a repeat rate of the order of a few tens to a few hundreds of megahertz, corresponding to the circulation (to and fro) time of the pulses in the resonator.

This high repeat rate implies that a laser of this type will emit low-energy light pulses. Nevertheless, this type of laser is adequate for many applications which require a high mean optical power but which can make do with low pulse energy, such as the LIDAR technology, or "linear" absorption spectroscopy, photoionization

spectroscopy, fluorescence spectroscopy, etc.

Moreover, lasers of pulsed type exist, which are characterized by a very low working cycle of the gain medium (of less than 1/50). This gain medium is activated for a short period, typically of less than one millisecond at a low repeat rate typically of a few tens of hertz. In pulsed mode, the gain medium may be temporarily very highly activated, corresponding to a large storage of optical energy in the gain medium, such that a mode-locked pulsed laser will be able to generate pulses of markedly greater energy than those generated by mode-locked lasers of continuous type. However, the fact, firstly, that the amplification factor of the gain medium is not constant during the transient activation period, and, secondly, that the stabilization of the optical oscillation in the laser cavity is a dynamic process which requires a certain amount of time and may thus be incomplete during the activation time of the gain medium, limits the efficiency of the mode-locking and consequently the brevity and energetic stability of said optical pulses generated.

Pulsed lasers are used in manufacturing processes which require high-energy optical pulses, such as for the ablation of materials, laser cutting and surface treatment, and also for "non-linear" optical spectroscopies such as multi-photon resonant ionization or frequency-sum generation spectroscopy, and also any technique requiring a low repeat rate of the laser (time-resolved measurements).

One way for mode-locking lasers of pulsed type is to insert a cell containing a dye (liquid solvent), optionally combined with an intensity limiter, into the laser cavity. This device has several drawbacks, in particular:

- the mobility and inhomogeneity of the solvent circulating in the cell are factors causing energy instability of the emitted pulses;

- the chemical or photochemical degradation of said dye makes it necessary for technicians to intervene regularly in order to optimize the mode-locking process.

Document US-A-4 914 658 describes a solid-state laser such as a Neodymium-doped Yttrium Aluminium Garnet (Nd:YAG) which is combined with a non-linear crystal and a dichroic mirror in order to create a non-linear optical means for mode-locking the laser. In the simplest embodiment of the device, the non-linear crystal makes it possible to generate a beam at the second harmonic from the fundamental beam amplified by the gain medium. The oscillation in the resonant cavity of the portion of the fundamental beam not converted by the non-linear crystal is negatively discriminated by means of a dichroic mirror which must have a reflection coefficient at the second harmonic frequency which is greater than that at the fundamental frequency.

Adjusting the optical distance between the non-linear crystal and the dichroic mirror makes it possible to obtain a suitable phase shift between the fundamental beam and the beam at the second harmonic, so as to obtain an efficient reconversion of the beam at the second harmonic into a fundamental beam in the non-linear crystal. This phase shift can also be obtained by inserting a transparent plate between the non-linear crystal and the dichroic mirror.

The non-linear optical means serves to increase the quality factor of the laser cavity, that is to say to reduce the energy losses of the laser beam by reflection against the dichroic mirror, when the instantaneous power of the beam at the fundamental frequency generated by the gain medium increases. In other words, the non-linear optical means induces a positive feedback on the quality factor of the laser cavity as a function of the

instantaneous power of the beam at the fundamental frequency.

The non-linear optical mode-locking device is also characterized in that the ratio of the beam power at the second harmonic relative to the beam power at the fundamental frequency increases as the power of the beam at the fundamental frequency increases.

Document EP-A-0 951 111 proposes a device and a method for mode-locking a laser, preferably also working in continuous mode, which are based on the principle described in document US-A-4 914 658. In this case, it is proposed to convert part of the laser beam at the fundamental frequency into a beam at the second harmonic by using a non-linear crystal. The oscillation in the resonant cavity of the part of the fundamental beam not converted in the non-linear crystal is negatively discriminated by means of the combination of a retardation plate and a polarizer. In said document, the gain medium is Nd:vanadate, the non-linear crystal is lithium triborate and the retardation plate has a retardation of $\lambda/4$ = 1064 nm and $\lambda/2$ = 532 nm. The retardation plate is placed between the non-linear crystal and the dichroic mirror, while the polarizer is placed between the gain medium and the non-linear crystal.

It is pointed out in said document that the dichroic mirror, placed behind the non-linear crystal, has a reflection coefficient at the second harmonic frequency which is not greater than the reflection coefficient at the fundamental frequency.

The non-linear optical means described in said document serves to increase the quality factor of the laser cavity, that is to say, to reduce the energy losses of the laser beam by reflection against the polarizer, when the instantaneous power of the beam at the fundamental frequency generated by the gain medium increases. In other words, the non-linear optical means induces a positive

feedback on the quality factor of the laser cavity as a function of the instantaneous power of the beam at the fundamental frequency.

The devices described in the two abovementioned documents US-A-4 914 658 and EP-A 0 951 111 allow the efficient mode-locking of continuous lasers. For example, pulses as short as ~10 picoseconds FWHM (full width at half maximum) can be generated when an Nd:YAG gain medium is used. However, these devices do not work properly in the case of pulsed lasers. The shortest pulse widths ever obtained by means of the device as described in document US-A-4 914 658 are 35 picoseconds FWHM (full width at half maximum) in the case of a pulsed Nd:YAG laser. These poor performance levels result from the fact that the gain factor of the active medium, the energy of the optical pulses and thus the conversion yield for the non-linear crystal used in the non-linear device vary greatly in the course of the activation period of the gain medium, which prevents any stabilization of the optical oscillation in the resonant cavity. Moreover, the small number of to-and-fro cycles within the cavity, and thus of interaction with the non-linear device, produced by the optical pulses during the activation time of the gain medium also limits the efficiency of the mode-locking.

Aims of the invention

The present invention aims to provide a device and a process for mode-locking a laser, making it possible to obtain particularly short pulses and having great energy stability, even in the case of a pulsed laser.

In particular, the present invention aims to overcome the drawbacks of the devices and processes of the prior art.

In particular, the present invention aims to propose a device consisting only of solid components, and

thus being simple to maintain when compared with devices using dyes (liquid solvents), and which is robust and inexpensive. In addition, the various constituents used will have to show a low level of degradation over time.

Main characteristic elements of the invention

The present invention relates to a device for mode-locking a laser, in particular a laser of pulsed type, comprising a laser cavity delimited by a first mirror and a second mirror, provided with an active medium for amplifying the laser beam at the fundamental frequency, and a solid non-linear optical means which comprises at least said second mirror and which has a reflection coefficient which increases as the beam intensity increases, characterized in that said device further comprises in the laser cavity a solid intensity limiter whose transmission coefficient of the fundamental beam decreases as the intensity of said laser beam increases.

More specifically, whereas the devices as described in document US-A-4 914 658 and EP-A-0 951 111 display, by using a non-linear optical means, only a positive feedback on the quality factor of the laser resonant cavity as a function of the power of the fundamental beam, the device according to the present invention displays, by the combined use of the non-linear optical means and the intensity limiter, both a positive feedback and a negative feedback on this quality factor. This is due to the fact that the non-linear optical means has a reflection coefficient which increases as the intensity of the fundamental beam increases, whereas the intensity limiter has a transmission coefficient at the fundamental frequency of the laser which decreases as the intensity of the fundamental beam increases.

The combined use of the non-linear optical means and the intensity limiter implies that the power ratio of

the beam at the second harmonic relative to the fundamental beam no longer increases as the intensity of the fundamental beam increases when said intensity exceeds the operating threshold of the intensity limiter.

Advantageously, the non-linear optical means comprises said second mirror which corresponds to a dichroic mirror and a non-linear crystal able to convert the laser frequency.

The non-linear optical means may also comprise only said second mirror, which then corresponds to a Fabry-Perot anti-resonant saturable absorber constructed from a superposition of dielectric or metallic semiconductor films.

The non-linear optical means may also comprise said second mirror which corresponds to a dichroic mirror, a frequency-converting non-linear crystal and at least one polarizer.

Advantageously, the intensity limiter consists of a plate made of a semiconductor material such as GaAs, CdSe or InP.

Alternatively, the intensity limiter consists of a non-linear crystal which converts the fundamental beam into a beam at a harmonic frequency.

Alternatively, the intensity limiter consists of an active device, that is to say an electronically controlled device which induces increasing energy losses in the cavity when the intensity of the fundamental beam increases, such as a Pockels cell or an acousto-optical modulator.

Advantageously, the intensity limiter is arranged between the gain medium and the non-linear optical means.

In a particularly advantageous manner, the intensity limiter and the non-linear optical means are arranged on either side of the gain medium.

The present invention also relates to a process for mode-locking a laser, in particular a laser of pulsed type, which comprises:

- emitting a laser radiation beam at the fundamental frequency by stimulating an active laser medium,
- converting the beam at the fundamental frequency into a beam at a harmonic frequency,
- returning the beam at the harmonic frequency to the resonant cavity,
- reconverting the beam at the harmonic frequency into a beam at the fundamental frequency,

intensity limitation of the beam at the fundamental frequency inside the resonant cavity.

Brief description of the drawings

Figure 1 describes one particular embodiment of the device for obtaining an Nd:YAG oscillator according to principle of the present invention.

Figure 2 represents the pulse train envelope obtained for the Nd:YAG oscillator as described in Figure 1.

Figure 3 represents the measurement of the pulse width which is carried out by a standard noise-free second-order auto-correlation.

Detailed description of one embodiment of the invention

Figure 1 describes, by way of example, one embodiment of the device according to the invention. In a conventional manner, firstly, a resonant cavity 20 delimited by a first mirror 1 and a second mirror 8 and, secondly, a non-linear optical means 10 comprising said second mirror 8 are produced. The first mirror 1 is of high, preferably total, reflection, and the second mirror 8 is a dichroic mirror. Inside the resonant cavity 20 is arranged an active medium 5 which may, in a conventional

manner, be an Nd:YAG (Neodymium-doped Yttrium Aluminium Garnet), Yb:YAG, Cr:YAG, Nd:YLF, Nd:glass, Ti:sapphire, Cr:forsterite or Yb:glass medium. The medium is adapted to emit, under stimulation, laser radiation at a fundamental frequency ω1. The choice of such a medium is dictated by the desired wavelength of the laser and the desired spectral width of the gain.

According to one embodiment of the invention, the gain medium is a bar of Nd:YAG crystal 5 with dimensions of 115 × 7 mm which is pumped by two flash lamps for stimulating a laser beam at a fundamental frequency ω1 = 1064 nm.

The energy of the electric pump is ~17 J, whereas the repeat frequency is 20 Hz.

Two lenses 61 and 62 provided with an anti-reflection coating and characterized, respectively, by focal distances of 100 and -40 mm form the telescope 6. A 0.8 mm diaphragm 3 limits the working of the laser to only one transverse mode. The intensity limiter intended for the active mode-locking according to this embodiment comprises an AOML (acousto-optical mode-locker) component 2 located close to the mirror of high reflection 1 and a GaAs plate 4. The total length of the cavity is approximately 1.5 m and is adapted to the 100 MHz modulation frequency of the AOML.

The non-linear optical means 10 comprises, in addition to the dichroic mirror 8, according to the embodiment represented in Figure 1, a non-linear crystal 7 of BBO type with a length of 3 mm, for generating a beam at the second harmonic (ω2 = 532 nm) by a type I interaction. The non-linear optical means 10 has a reflection coefficient of greater than 99% at 532 nm and equal to 25% at 1064 nm. Other non-linear crystals may be used, such as LBO (lithium triborate), KDP (potassium dihydrogen phosphate), KTP (potassium titanyl phosphate), BBO (beta-

barium borate), PPLN (periodically poled lithium niobate) or $KNbO_3$ (potassium niobate). The GaAs plate is aligned at the Brewster incident angle. Adjustment of the distance separating the non-linear crystal 7 of the dichroic mirror 8 allows the phase shift between the fundamental beam and the beam at the second harmonic to be controlled during the reconversion process.

When this distance is correctly adjusted, an appreciable increase in the intensity of the beam generated by the cavity is observed, which reveals the efficient passive mode-locking of the YAG oscillator.

The mean output power of the laser cavity is -30 mW (pulse train energy = 1.5 mJ) for an electric pump energy of -17 J when the AOML component 2 is used in the cavity.

Figure 2 represents the 2 μs long pulse train envelope as measured by a p-i-n photodiode with an oscilloscope bandwidth of 60 MHz. The first part of the envelope (0 - 500 ns) is characterized by a rapid variation in the pulse energy and is followed by a plateau from 600 to 1800 ns characterized by a virtually constant pulse energy, estimated to be 10 μJ/pulse.

Although previous studies revealed that this device could work without active mode-locking, much more stable working of the YAG oscillator has been observed when the AOML component is used in the cavity.

Figure 3 shows the measurement of the pulse width at the centre of the plateau of the train envelope. This measurement is performed by noise-free standard second-order auto-correlation by synchronizing the 50 ns window of the auto-correlation signal integrator with the centre of the stable plateau of the train envelope.

Assuming a gaussian distribution, a pulse width of 12 ps FWMH is deduced for the fundamental pulse. The peak intensity inside the cavity reaches a value of the

order of 55 MW/cm^2, which is in accordance with the start of the two-photon absorption in a GaAs semiconductor.

In conclusion, it is possible to obtain a pulse width reduced to 12 ps or even less using a pulsed Nd:YAG laser pumped with a flash lamp, by combining a passive negative feedback component constituting the intensity limiter, which is a GaAs plate in the present case, with a positive feedback component, which is a non-linear optical means in the present case, consisting of a frequency-doubling non-linear crystal (BBO) coupled to a dichroic mirror.

The increase in the number of to-and-fro cycles performed by the optical pulses and also their energy stabilization induced by the intensity limiter are two key factors for obtaining short pulses. The width of these pulses is very close to the lower limit of ~10 ps, set by the Fourier transform of the gain spectrum of the Nd:YAG gain medium.

The pulsed laser equipped with the device described in the present document has ideal characteristics for the synchronous pumping of an optical parametric oscillator.

Moreover, the interposition, inside or outside the cavity, of passive and active components for polarization selection and modification, such as a Pockels cell, polarizers and retardation plates, will make it possible to select energetic single pulses.

ART 34 AMDT

CLAIMS

1. Device for mode-locking a laser, in particular a laser of pulsed type, comprising a resonant cavity (20),

- delimited by a first mirror (1) and a second mirror (8),
- provided with an active laser gain medium (5) for amplifying a laser radiation beam at the fundamental frequency ($\omega 1$), and
- with a solid non-linear optical means (10) which comprises at least said second mirror (8), for reversible conversion of the radiation at the fundamental frequency ($\omega 1$) into radiation at a harmonic frequency ($\omega 2$), said non-linear optical means having a reflection coefficient which increases as the intensity of the radiation at the fundamental frequency increases,

said device further comprising arranged in the resonant cavity (20) a solid intensity limiter (4) whose transmission coefficient of the laser radiation decreases as the intensity of said radiation increases, **characterized in that said intensity limiter (4) comprises a GaAs, CdSe or InP plate.**

2. Device according to Claim 1, characterized in that the non-linear optical means (10) comprises said second mirror (8) which corresponds to a dichroic mirror and a non-linear crystal (7) able to convert the radiation at the fundamental frequency into radiation at a harmonic frequency.

3. Device according to Claim 1, characterized in that the non-linear optical means (10) comprises said second mirror (8) which corresponds to a dichroic mirror, a non-linear crystal (7) able to convert the radiation at the fundamental frequency into radiation at a harmonic frequency, and at least one component for polarization selection and/or modification.

4. Device according to Claim 2 or 3, characterized in that said non-linear crystal is a BBO crystal.

5. Device according to Claim 1, characterized in that the non-linear optical means (10) comprises only the second mirror (8), said second mirror corresponding to a Fabry-Perot anti-resonant saturable absorber constructed from a superposition of dielectric or metallic semiconductor films.

6. Device according to one of the preceding claims, characterized in that the intensity limiter (4) and the non-linear optical means (10) are placed on either side of the active gain medium (5).

7. Device according to one of the preceding claims, characterized in that the intensity limiter (4) is placed between the non-linear optical means (10) and the active gain medium (5).

8. Device according to one of the preceding claims, characterized in that the active gain medium is an Nd:YAG crystal.

9. Device according to one of the preceding claims, characterized in that the non-linear optical means (10) has a reflection coefficient of the radiation at the second harmonic ($\omega 2$) which is greater than the reflection coefficient of the radiation at the fundamental frequency ($\omega 1$).

10. Device for mode-locking a laser, in particular a laser of pulsed type, comprising a resonant cavity (20),

- delimited by a first mirror (1) and a second mirror (8),
- provided with an active laser gain medium (5) for amplifying a laser radiation beam at the fundamental frequency ($\omega 1$), and
- a solid non-linear optical means (10) which comprises at least said second mirror (8), for reversible conversion

of the radiation at the fundamental frequency ($\omega 1$) into radiation at a harmonic frequency ($\omega 2$), said non-linear optical means (10) having a reflection coefficient which increases as the intensity of the radiation at the fundamental frequency increases,

characterized in that said device is provided with an intensity limiter comprising a GaAs, CdSe or InP plate with a transmission coefficient which decreases as the intensity of the radiation at the fundamental frequency increases, so as to ensure, in combination with said non-linear optical means (10), both a positive feedback and a negative feedback on the quality factor of the resonant cavity (20).

11. Process for mode-locking a laser, in particular a laser of pulsed type, characterized in that it comprises:

- emitting a laser radiation beam at the fundamental frequency ($\omega 1$) by stimulating an active laser medium (5),
- converting the beam at the fundamental frequency ($\omega 1$) into a beam at a harmonic frequency ($\omega 2$),
- returning the beam at the harmonic frequency ($\omega 2$) to the resonant cavity (20),
- reconverting the beam at the harmonic frequency ($\omega 2$) into a beam at the fundamental frequency ($\omega 1$), and
- limiting the intensity of the beam at the fundamental frequency ($\omega 1$) inside the resonant cavity (20), by means of at least one GaAs, CdSe or InP plate.

Legend for Fig. 3

Intensité de second harmonique → Intensity of the second harmonic

u.a. → a.u.

Temps → Time

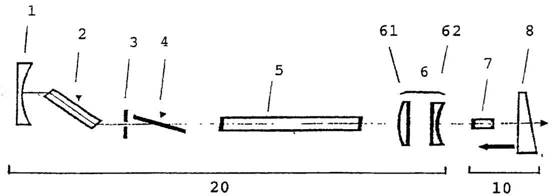

FIG. 1

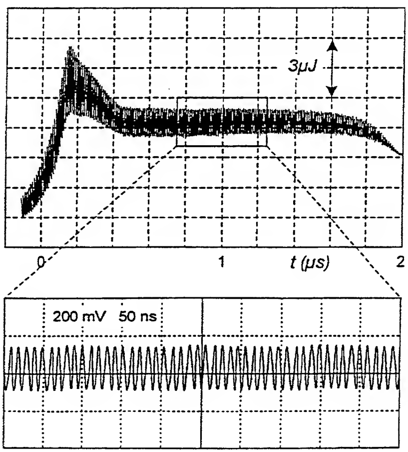

FIG. 2

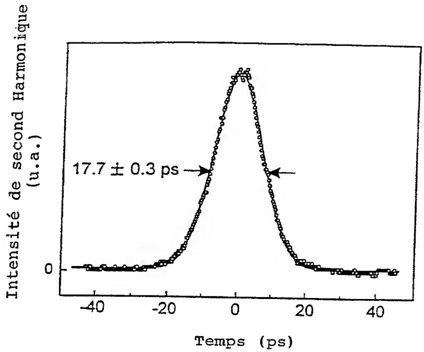
Intensité de second Harmonique (u.a.)
17.7 ± 0.3 ps
0
-40
-20
0
20
40
Temps (ps)

FIG. 3

Declaration and Power of Attorney for Patent Application

Déclaration et Pouvoirs pour demandes de brevet

French Language Declaration

En tant que l'inventeur nommé ci-après, je déclare par le présent acte que :

As a below named inventor, I hereby declare that :

Mon domicile, mon adresse postale et ma nationalité figurant ci-dessous à côté de mon nom,

My residence, post office address and citizenship are as stated below next to my name,

Je crois être le premier inventeur original et unique (si un seul nom est mentionné ci-dessous), ou l'un des premiers co-inventeurs originaux (si plusieurs noms sont mentionnés ci-dessous) du sujet revendiqué, pour lequel une demande de brevet a été déposée concernant l'invention intitulée :

I believe I am the original, first and sole (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled :

DEVICE AND METHOD FOR A LASER BLOCKED-MODE

et dont les caractéristiques sont fournies ci-joint à moins que la case suivante n'ait été cochée :

the specification of which is attached hereto unless the following box is checked :

O a été déposé le
sous le numéro de Demande des Etats-Unis ou sous le numéro de demande internationale PCT et modifiée le (le cas échéant).

☒ was filed on 3 May 2000
as United States Application Number or PCT International Application Number
PCT/BE00/00049 and was amended on (if applicable).

Je déclare par le présent acte avoir passé en revue et pris connaissance du contenu des caractéristiques ci-dessus, revendications comprises, telles que modifiées par tout amendement dont il aura été fait référence ci-dessus.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

Je reconnais de voir divulguer toute information pertinente à l'examen de cette demande, comme le définit le Titre 37, §1.56 du Code fédéral des réglementations.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, § 1.56.

French Language Declaration

Je revendique par le présent acte avoir la priorité étrangère, en vertu du Titre 35, § 119 du Code des Etats-Unis, sur toute demande étrangère de brevet ou certificat d'inventeur figurant ci-dessous et ai aussi pris connaissance de toute demande étrangère de brevet ou de tout certificat d'inventeur ayant une date de dépôt précédant celle de la demande à propos de laquelle une priorité est revendiquée.

I hereby claim foreign priority under Title 35, United States Code, § 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed.

Prior foreign applications
Demande(s) de brevet antérieure(s)

			Priority claimed / Droit de priorité revendiqué	
BE 9900314	Belgium	3 May 1999	⊗	O
(Number) (Numéro)	(Country) (Pays)	(Day/Month/Year Filed) (Jour/Mois/Année de dépôt)	Yes Oui	No Non
			O	O
(Number) (Numéro)	(Country) (Pays)	(Day/Month/Year Filed) (Jour/Mois/Année de dépôt)	Yes Oui	No Non
			O	O
(Number) (Numéro)	(Country) (Pays)	(Day/Month/Year Filed) (Jour/Mois/Année de dépôt)	Yes Oui	No Non

Je revendique par le présent acte tout bénéfice, en vertu du Titre 35, § 120 du Code des Etats-Unis, de toute demande de brevet effectuée aux Etats-Unis figurant ci-dessous et, dans la mesure où le sujet de chacune des revendications de cette demande de brevet n'est pas divulgué dans la demande américaine préalable, en vertu des dispositions de premier paragraphe du Titre 35, § 112 du Code des Etats-Unis, je reconnais devoir divulguer toute information pertinente à la demande de brevet comme défini dans le Titre 37, § 1.56 du Code fédéral des réglementations, dont j'ai pu disposer entre la date de dépôt de la première demande et la date de dépôt de la demande nationale ou PCT internationale :

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, § 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application :

(Application Serial No.) (No. de série de la demande)	(Filing date) (Date de dépôt)	(Statut) (Breveté, en attente, annulé)	(Status) (Patented, pending, abandoned)
(Application Serial No.) (No. de série de la demande)	(Filing date) (Date de dépôt)	(Statut) (Breveté, en attente, annulé)	(Status) (Patented, pending, abandoned)

Je déclare par le présent acte que toute déclaration ci-incluse est, à ma connaissance, véridique et que toute déclaration formulée à partir de renseignements ou de suppositions est tenue pour véridique; et de plus, que toutes ces déclarations ont été formulées en sachant que toute fausse déclaration volontaire ou son équivalent est passible d'une amende ou d'une incarcération, ou des deux, en vertu de la Section 1001 du Titre 18 du Code des Etats-Unis et que de telles déclarations volontairement fausses risquent de compromettre la validité de la demande de brevet ou du brevet délivré à partir de celle-ci.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful and false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application of any patent issued thereon.

French Language Declaration

POUVOIRS : En tant que l'inventeur cité, je désigne par la présente l'(les) avocat(s) et/ou agent(s) suivant(s) pour qu'il(s) poursuive(nt) la procédure de cette demande de brevet et traite(nt) toute affaire avec le Bureau des brevets et marques s'y rapportant.

(mentionner le nom et le numéro d'enregistrement)

POWER OF ATTORNEY : As named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and trademark Office connected there with.

(list name and registration number)

Adresser toute correspondance à :

Send Correspondence to :

Adresser tout appel téléphonique à :
(nom et numéro de téléphone)

Direct Telephone Calls to :
(name and telephone number)

Nom complet de l'unique ou premier inventeur	Full name of sole or first inventor PEREMANS André
Signature de l'inventeur Date	Inventor's signature Date
Domicile	Residence Chemin du Gros Buisson 23, B-5020 MALONNE (Belgium) BEX
Nationalité	Citizenship citizen of Belgium
Adresse postale	Post Office Address Chemin du Gros Buisson 23, B-5020 MALONNE (Belgium)

01/10/2001

(Fournir les mêmes renseignements et la signature de tout co-inventeur supplémentaire)

(Supply similar information and signature for any subsequent joint inventor)

Nom complet du second co-inventeur, le cas échéant	Full name of second joint inventor, if any MANI Alaa Addin
Signature du second inventeur Date	Second inventor's signature Date 04/10/200
Domicile	Residence rue J. Grafé, 4/201, B-5000 NAMUR (Belgium)
Nationalité	Citizenship citizen of Syria
Adresse postale	Post Office Address rue J. Grafé, 4/201, B-5000 NAMUR (Belgium)

Nom complet du troisième co-inventeur, le cas échéant	Full name of third joint inventor, if any THIRY Paul
Signature du troisième inventeur Date	Third inventor's signature Date Paul Thiry 04/10/2001
Domicile	Residence avenue Joséphine Charlotte, 58, B-1330 RIXENSART (Belgium)
Nationalité	Citizenship citizen of Belgium
Adresse postale	Post Office Address avenue Joséphine Charlotte, 58, B-1330 RIXENSART (Belgium)

Nom complet du quatrième co-inventeur, le cas échéant	Full name of fourth joint inventor, if any
Signature du quatrième inventeur Date	Fourth inventor's signature Date
Domicile	Residence
Nationalité	Citizenship
Adresse postale	Post Office Address